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TECHNOLOGICAL PROBLEMS IN THE PROCESSING OF SOYBEANS 1/

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I. The Continuous Pressing Method

In order to consider a few of the technologic problems involved in the processing of soybeans, it will be necessary to describe the various methods used for removing oil from the beans and to consider the different kinds of machinery employed. By processing, we mean the operation of producing crude soybean oil and soybean oil meal from soybeans. The oil is subsequently refined and consumed principally in the edible oil and, to a lesser extent, in the drying oil industries, while the meal is utilized as a protein concentrate for mixed feeds. The much-publicized industrial uses of soybean protein, while offering a vast potential outlet, at present account for a relatively small percentage of the soybean oil meal consumption.

The path of the beans through a typical processing plant leads first to the elevator which may range in size from a bin containing a few thousand bushels to a terminal elevator holding millions of bushels. Soybean storage in itself is not a difficult problem, and commercial practice differs very little from that of storing grains. It is necessary to remove weed seeds and foreign material and to run the beans into the bins at a moisture content of about 13 percent or lower to avoid heating. It is possible, but not always considered safe, to store soybeans for short periods or in small batches at higher moisture percentages. When it is necessary to dry soybeans before storage, direct heat driers of the baffle type, identical with those used on grains, are considered quite satisfactory.

Not a great deal is known concerning the effects of length and conditions of storage upon the yield and quality of the products resulting from processing. Distinct changes do occur throughout the storage year, and the proper evaluation of these changes, together with their effects upon the resulting products, is one of the industry's present problems. Soybean storage has reached a point of perfection far beyond that of most other oleaginous materials, but the possibilities for further improvements

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furnish plenty of food for thought and are not being overlooked.

From storage, the path of soybeans through the mill depends upon the process employed. That most widely used in this country is known as continuous pressing, and next in importance is continuous solvent extraction. Although hydraulic presses and, to a small extent, batch solvent extractors are also operated, the present-day trend is definitely away from methods requiring large amounts of hand labor. We shall therefore confine these remarks to the first two, that is, the continuous methods.

In continuous pressing mills, cleaned beans from the storage bins are run to cracking mills which consist of two or three pairs of corrugated rolls, as shown in Figure 1, which reduce the size to an average of roughly 10 mesh. This treatment is followed by drying to a moisture content of 2 to 5 percent in rotary steam driers, a typical installation of which is shown in Figure 2. The hot, dry material is then conveyed to the presses.

Continuous presses used on soybeans in this country are the Anderson Expeller and the French Screw Press. Figure 4 shows structural features of the Super-Duo, an expeller which is widely used on soybeans. The granular material, hot from the driers, enters the uppermost of three tempering troughs and is slowly conveyed through them, in succession, being cooked at a high temperature by means of steam jackets. The individual particles are thus permitted to equalize the unsteady state of moisture and heat distribution existing immediately after the drying operation and thus reach the press itself without serious gradients of temperature and moisture content in the single small grains.

The pressing is done by a worm revolving inside a steel cage, the operation being, to some extent, analogous to that of a household meat grinder. The cylindrical cage, or drainage barrel, is composed of longitudinal, parallel steel bars, closely spaced, between which the oil flows when squeezed out under the influence of pressure developed within the barrel. The pressure may be as high as 10 tons per square inch and is produced partly because of the irregular shape of the worm shaft and partly because of flow restriction by means of an adjustable orifice at the end where the pressed cake is discharged. The flow of oil from the beans under pressure is facilitated by increased temperatures due to friction developed by the action of the screw.

The cake emerges as irregularly shaped, hard fragments which have been toasted to a brown color by heat developed during the operation. Large masses of cake, if stored hot, will rapidly heat still further to the ignition point, and the cake must therefore be cooled to a safe temperature by adding water and blowing air through it. The final step in preparation of soybean oil meal consists in grinding the cake in a hammer mill.

Oil from the press is run over a shaking or revolving screen or similar straining device to remove small meal particles, or foots, which are returned to the feed. The strained oil is filtered, generally through a filter press, and marketed as crude soybean oil.

The French Screw Press is also widely used on soybeans. Its principle of operation is much the same as that of the Super-Duo, but it differs considerably in details of construction. Operating results are approximately the same with either machine, the capacity being about 750 bushels per day. A bushel of beans containing approximately 20 percent of oil yields 8 to 10 pounds of crude oil and close to 50 pounds of meal containing about 4.5 percent oil and 40 to 45 percent protein. Figure 3 shows the interior of a mill using French Screw Presses.

II. The Solvent Process

In solvent extraction processes, instead of being cracked, the beans are rolled into thin flakes in order to create a high specific surface without introducing excessive fines which would clog filters and other parts of the system. The flaking operation is, in most cases, preceded by cracking and heating and, occasionally, by addition of moisture. Smooth rolls are employed, one pair high, having diameters of 18 to 36 inches, and the flakes produced range in thickness from 6 to 15 thousandths of an inch, depending upon the type of extractor used.

The Bollman system is shown diagrammatically in Figure 5. The flakes are introduced into baskets with perforated bottoms which hang between a pair of endless chains comprising two vertical legs, one descending and one ascending. The chain rotates in a clockwise direction making a complete revolution in about one hour. Baskets are filled at the top of the right-hand or downcoming leg, and are dumped when they reach the top of the rising leg. The extraction is accomplished by means of hexane or similar solvent which is sprayed over the top basket on either side, percolating through lower baskets in succession. Freshly redistilled solvent runs in counter-current flow down through the ascending chain of baskets and the resulting solution, known as half-miscella, is collected and pumped to the to the top of the downcoming side so that it washes the descending baskets in parallel flow. The final solution of 20 to 25 percent oil in solvent which accumulates at the bottom of the descending side is known as full-miscella, and, after it has been filtered, the solvent is evaporated, condensed, and returned to the system. The final operation in the preparation of crude oil is the removal of traces of solvent by means of a stripping column.

The extractor proper is enclosed by a gas-tight steel housing into which fresh flakes are charged and from which extracted meal is discharged by the mechanisms shown in Figure 6. The extracted solids are fed immediately into steam driers which drive off entrained solvent and discharge finished meal containing well under one percent of residual oil.

The Bollman or Hansa-Muhle system, as just described, has been built in sizes having capacities of 25 to 400 tons per day, and, with the exception of the extractor proper, is typical of most extraction systems. Each process, however, resorts to a distinctly different method for contacting the bean flakes with solvent. Of special importance in this country is the Hildebrandt system which is shown in Figure 7. Flaked beans are

introduced at "20" through the top of the left leg of a U-shape double column, and are slowly propelled downward, then horizontally toward the right, and then vertically upward through the right-hand leg by means of perforated revolving screw conveyors. Extracted meal is discharged at "17" from the top of the right-hand leg into the driers. Solvent is introduced into the same leg at "15", somewhat below the meal exit, and flows through the system countercurrent to the flakes, overflowing through miscella pipes at "13" somewhat below the top of the left worm flight.

In this process, the extraction is effected by complete immersion in liquid solvent as contrasted to the percolation action occurring in the Bollman system. Figure 8 shows an installation of two Hildebrandt units. The batteries of horizontal drums shown between the two extractors are meal driers used to drive off all entrained solvent. These extractors are built in two sizes having capacities of 55 and 110 tons per day, and are frequently used in multiple installations consisting of two or more units.

The Ford Motor Company's extraction system is an attempt to develop a continuous extraction apparatus having the advantages of larger plants but built in a unit small enough to operate as a community plant. The extractor consists of an inclined tube partly filled with solvent through which a modified screw conveyor propels soybean flakes upward while solvent passes downward in countercurrent flow. The upper part of the shell is steam jacketed and serves to remove most of the solvent, the remainder of which is driven off in another inclined tube, or steamer, located immediately below the upper portion of the extractor tube. Solvent is distilled from the miscella and is subsequently condensed and returned to the system. Figure 10 shows the interior of one of the Ford experimental plants which consists of two extractors, each having a capacity of 6 tons per day.

The Allis-Chalmers system is also used on soybeans and is shown in Figure 9. The extractor consists of a vertical cylinder having circular plates between stationary scraper arms, the plates rotating at slow speed about a central shaft. Flakes are introduced at the top and pass downward, dropping through slots in successive plates so staggered that the material travels in a helical path. Solvent is introduced at the bottom and flows upward in a similar spiral course, overflowing through the miscella outlet connection shown near the top of the column. The extracted flakes settle into the bottom of the column where they are discharged by means of a revolving screw which forces the meal through an adjustable spring-loaded cone valve. This mechanism forms the extracted material into a solid plug, squeezing out most of the solvent and preventing the bulk of the solvent in the column from running out along with the flakes. Extractors of this type have been built with a capacity of 50 to 75 tons per day.

The French Oil Mill Machinery Company has recently entered the field of continuous solvent extraction. In general, their equipment resembles that of the German-manufactured Bollman system. The Kennedy extractor

and the system developed by the E. I. du Pont de Nemours and Company, Inc., also deserve mention, although neither is yet in commercial operation on soybeans.

With the exception of adhesives, most industrial products derived from soybean protein require the use of solvent-extracted meal, since the higher oil content of pressed cake generally imparts undesirable properties to plastics and like products. Solvent extraction of soybeans to yield a protein conforming to industrial requirements should preferably be carried out under conditions somewhat different from those ordinarily employed when the meal is intended for feeding; otherwise the protein may become denatured by overheating. This is a relatively new problem concerning which not a great deal of information is available.

On the other hand, solvent-extracted meal for use in feeds requires a vigorous toasting process following the extraction in order to increase its nutrient value and palatability. It is the recent introduction of toasting methods which has largely accounted for the abatement of long-standing prejudice against the use of solvent-processed meal in feeds.

III. Solvents for Soybean Oil Extraction

An ideal solvent for extracting oil from soybeans should be capable of penetrating the bean flakes and rapidly dissolving and removing the oil and only the oil. Obviously, it must also be easily removable from the oil and the meal, leaving both products in satisfactory form for consumption. Other factors entering into the choice include cost, ease of recovery, fire and explosion hazard, corrosiveness, toxicity, and boiling range.

Apparently, there is only one extraction plant in the world now processing soybeans on a commercial scale with any solvent other than petroleum fractions. The single exception is a Manchurian plant using absolute ethyl alcohol. In this country, most of the solvent consists of hexanes, a typical commercial grade of which has a boiling range of 146° to 158° F. and a specific gravity of 0.685 at 60° F. In Europe, it is the usual practice to employ a hydrocarbon boiling between 160° and 195° F. These petroleum products are excellent fat solvents, and they can be quite readily removed from both the oil and the meal without impairing the qualities of the products. Above all, they are relatively cheap and available in large quantities. In recent years, several of the petroleum companies have placed on the market hydrocarbons possessing narrow boiling ranges and relative freedom from nonvolatile contaminants.

Such solvents are so flammable that their use by any but experienced operators is hazardous, and modern extraction plants are accordingly designed to afford the greatest possible protection from explosions. Buildings should be well ventilated and provided with large areas of windows designed to open or shatter easily in order to relieve pressure in the event of an explosion. The plant should be located at some distance

from the power house, and no open lights, flames, etc., should be permitted in the vicinity. Motors and related electrical equipment must be explosion proof, and electric wiring must conform to requirements of the National Electrical Code. Only sparkproof tools should be used in the building, and hobnailed shoes, matches, and similar articles should be forbidden. Floors and stairways should be of the grating type.

Many solvents have been proposed and used experimentally in efforts to reduce the danger of extractor operation. Of these, the chlorinated hydrocarbons have received a great deal of attention. The R. and H. Chemicals Department of the E. I. du Pont de Nemours and Company, Inc., has developed an extraction system particularly suited to trichloroethylene. It consists of an inclined helical conveyor which carries the flaked beans downward against a rising stream of solvent. Its operation is approximately the reverse of that employed in the Ford extractor since, unlike hexane, trichloroethylene is heavier than soybean oil.

At present, the principal deterrent to general use of trichloroethylene instead of hexane is its comparatively high cost. It should not be overlooked as a possible solvent for soybean oil, however, because it is entirely nonflammable and nonexplosive. Dry cleaning and metal degreasing industries use it extensively for this reason, and it is likewise used in extraction of caffeine from coffee.

A number of patents have been issued on the use of liquid propane and other low-boiling hydrocarbons as oil solvents. These materials are so volatile that the equipment must be designed for operation under pressure. The solvents which are mentioned in the literature, particularly in patents, comprise a very long list. Besides the patents specifying the more conventional solvents such as benzene, carbon tetrachloride, carbon disulphide, etc., other patents have been granted for the use of materials like furfural and sulphur dioxide as solvents for extracting fats and oils from the raw materials.

The importance of the corrosive properties of any given solvent is difficult to evaluate. Corrosion is a problem in the edible oil industry not primarily from the standpoint of damage to equipment but mainly through the tendency of infinitesimal traces of metallic contaminants to impair the keeping qualities of the finished products. It is well known, for example, that less than one part per million of copper in some edible oils will markedly decrease their stability as regards taste and suitability. It is of utmost importance, then, that solvents used for soybean extraction be entirely noncorrosive toward the metals with which they come into contact.

It is difficult to predict whether hexane and similar hydrocarbons will continue to be the only solvents used in this country for the extraction of soybean oil. At the present time, the most promising competitors of hexane appear to be ethyl alcohol and trichloroethylene. The properties of these materials are shown in Table I.

Table I.--Properties of some commercial grade solvents.

	Formula	Boiling range, °F.	Specific gravity
Normal hexane	C_8H_{14}	146-158	0.685/60°F.
Ethyl alcohol	C_2H_5OH	173	1.472-1.476/15°/4°C.
Trichloroethylene	C_2HCl_3	187-189	0.7994/15°/4°C.

Hot Alcohol Process

When soybean oil is dissolved in absolute ethyl alcohol at temperatures higher than about 150°F., a homogeneous solution is obtained. Upon cooling, two layers form, the lower one consists chiefly of soybean oil with a small amount of alcohol and the upper one is mainly alcohol containing a small amount of oil. The relative amounts of the two layers and their compositions depend upon the original solvent-oil ratio, the proof of the alcohol, and the extraction temperature.

This property has been utilized in the so-called "hot alcohol" process by the Manchuria Soybean Industry Company which operates a large extraction plant at Dairen. The installation has a daily capacity of approximately 100 tons of beans which are processed in a battery of rotary extractors. The solvent is 99.8 percent ethyl alcohol which is dehydrated at the plant. The beans are selected, cleaned, and if necessary warmed slightly before flaking. Since absolute ethyl alcohol is a dehydrating agent and loses its solvent power toward soybean oil in the presence of water, the flaked beans are dried prior to the extraction. They are then charged into the extraction battery and leached with the hot alcohol under pressure.

The resulting miscella is cooled and pumped into a conical separating tank where oil containing 5 percent alcohol collects in the bottom. It is drawn off, and the solvent is removed in an evaporator. The recovered oil is of semi-refined quality, having a light yellow color and salty taste, and can be used for edible purposes without further refining. The supernatant alcohol in the settling cone is returned to the extraction system, or when it becomes too contaminated with water or nonoil extractables, it is transferred to a still for recovery of the byproducts and subsequent rectification of the alcohol. The byproducts include sugars, saponins, and phosphatides. The residual meal contains 0.5 to 1.0 percent oil and requires no refining for use in a variety of foodstuffs. It reportedly commands a price 25 percent higher than that of meal produced by other methods. Furthermore, it is said to possess properties which make it especially suited for the production of industrial proteins.

The principal advantage of the alcohol extraction method is the ease of byproduct recovery. However, the American market for the above-named byproducts is not highly developed and there has therefore been little

incentive toward the introduction of the process into this country. At present, the general use of any solvent which extracts appreciable quantities of nonoil substances along with the oil faces considerable restriction because of the relatively limited markets for such byproducts. The cost of alcohol relative to that of hydrocarbons, the relatively high latent heat of evaporation of ethyl alcohol, and the high initial cost of the equipment have been additional deterrents to the development of the alcohol extraction process in the United States.

A large amount of experimental work has been done on the use of ethanol-benzene and methanol-benzene mixtures for soybean extraction in cases where phosphatides are to be recovered. During the late 1920's such mixtures were employed for a while in the huge plant of Hansa-Mühle, A. G. in Hamburg. At about the same time, a small extraction plant in Monticello, Illinois, operated with benzene as a solvent.

Liquid-Liquid Extraction

Ethyl alcohol is only one of a class of solvents which in certain temperature ranges are only partly miscible with soybean oil. Others include furfural, methyl alcohol, ethyl acetoacetate, acetic acid, etc. The portion of soybean oil which dissolves in these solvents has a slightly higher iodine number than has that portion which remains undissolved. By contacting the oil and solvent in countercurrent flow, it is possible to fractionate the soybean oil into two products, one having a high iodine number and the other having a low iodine number. The former is an excellent drying oil, far superior in this respect to the original oil, and the latter fraction is a good edible oil. This new method of solvent extraction has been studied extensively at the U. S. Regional Soybean Industrial Products Laboratory and shows great promise as a means for diverting a substantial part of our soybean oil out of the crowded edible product fields of consumption into industrial channels. It may, too, aid in averting a possibly serious shortage of drying oils resulting from the temporary cessation of imports of these materials from South America and the Orient. The process should not be confused with the solvent extraction of oil from the beans. It is an extraction method to which the oil may be subjected as one step in its refining, and the solvents suitable for carrying out the process are generally somewhat different in their properties from the solvents used to extract the oil from the beans. Although liquid-liquid extraction of soybean oil is not yet being carried out commercially, it is reasonable to expect industrial developments along this line in the not too distant future.

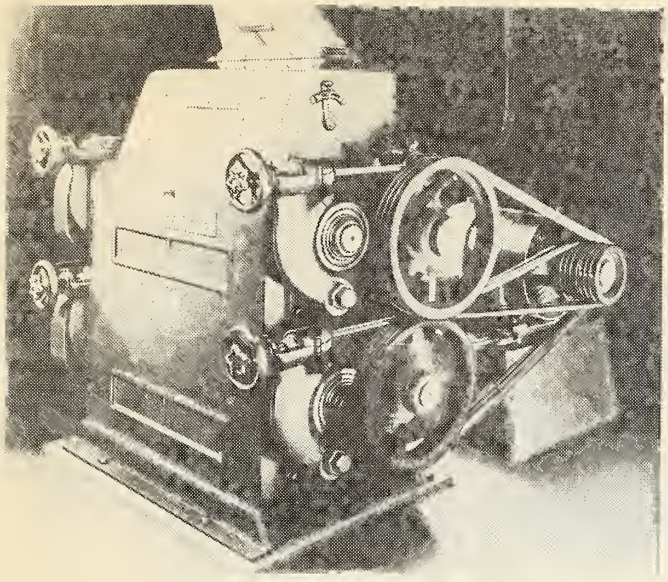

Figure 1.-A roller mill for cracking soybeans prior to pressing. (Courtesy Allis-Chalmers Manufacturing Company.)

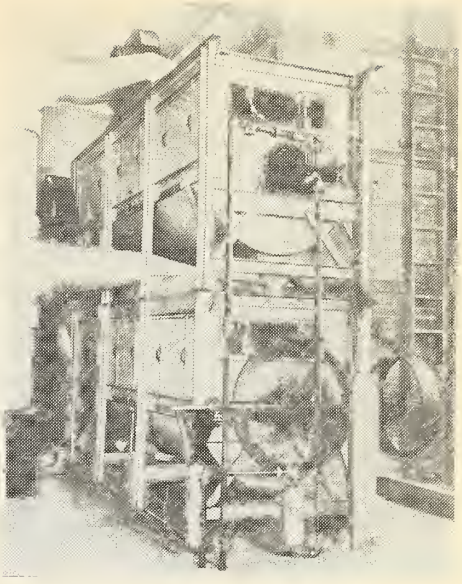

Figure 2.-A rotary steam drier used to remove moisture from cracked soybeans before pressing. (Courtesy of Allis-Chalmers Manufacturing Company.)

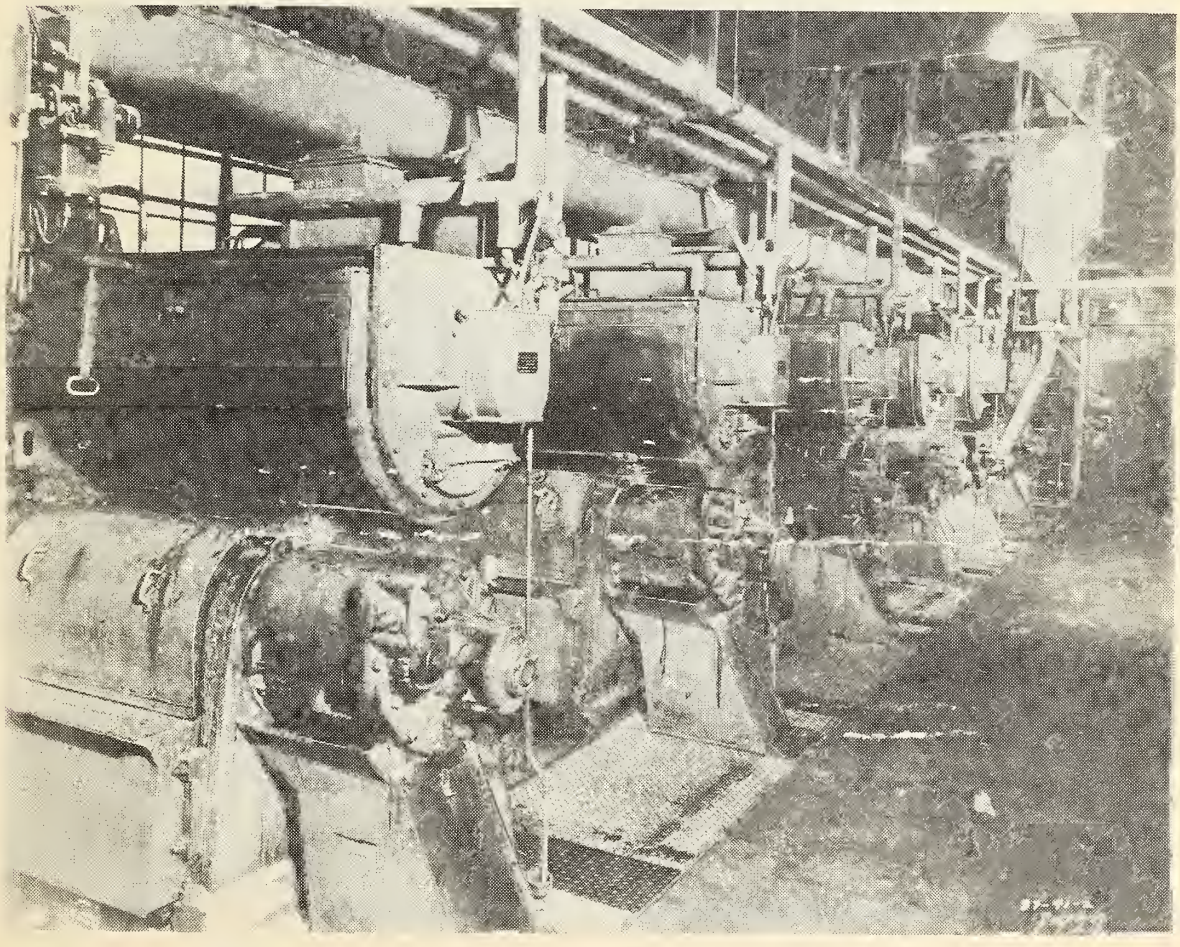

Figure 3.-Interior of a soybean processing mill using French Screw Presses. (Courtesy of French Oil Mill Machinery Company.)

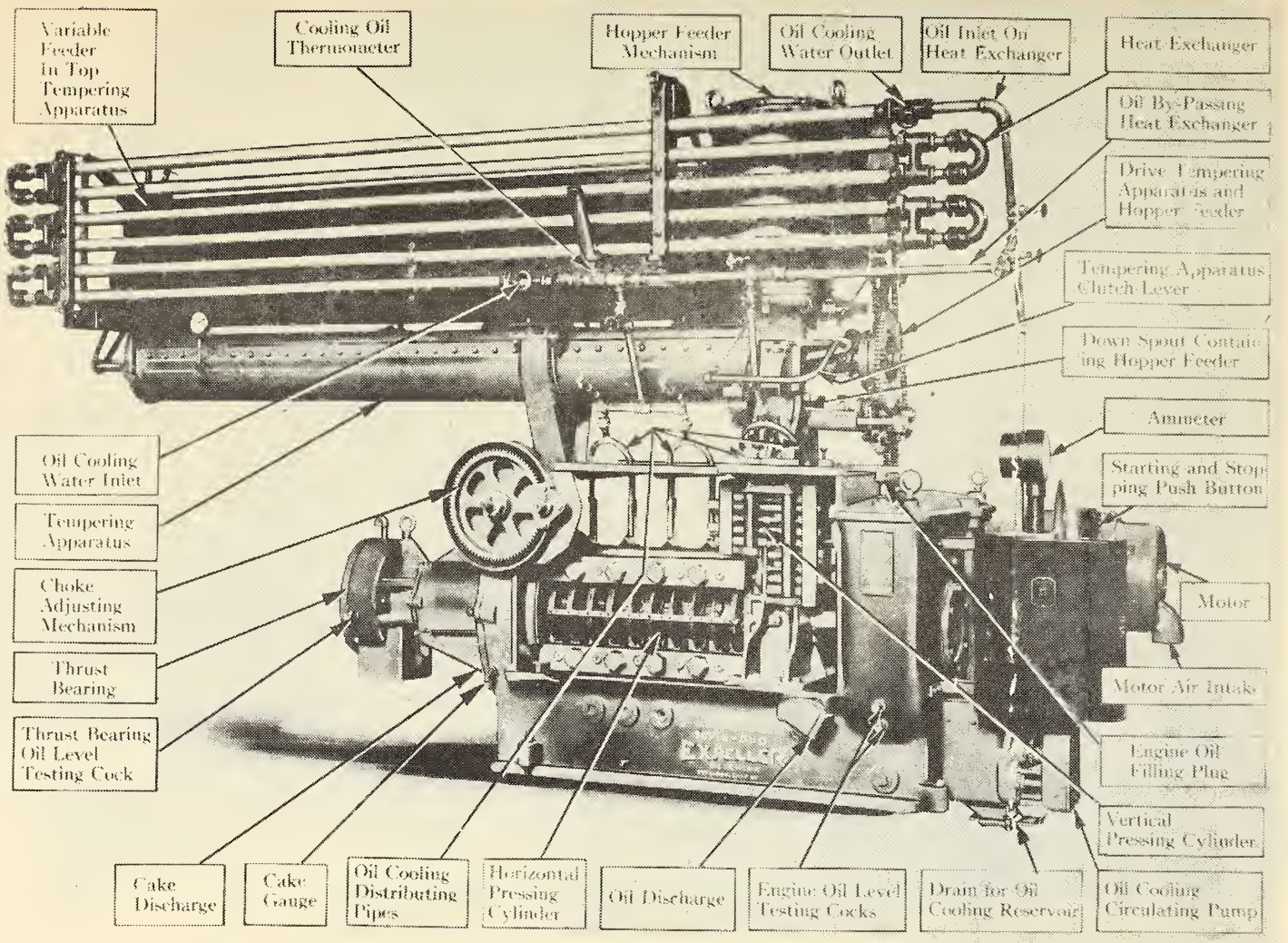

Figure 4.-The Anderson Super-Duo expeller.(Courtesy of V. D. Anderson Company.)

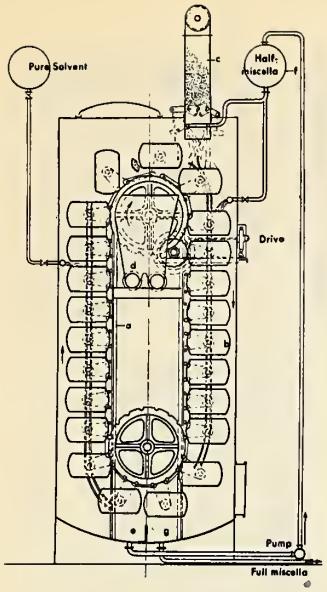

Figure 5.-The Bollman or Hansa-Mühle system of extraction. (Courtesy of Albert H. Bruecke.)

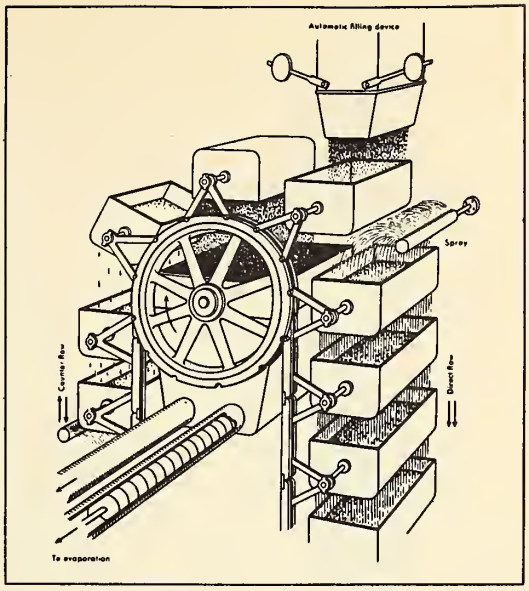

Figure 6.-Mechanism for charging and discharging baskets in the Bollman extraction system.(Courtesy of Albert E. Bruecke.)

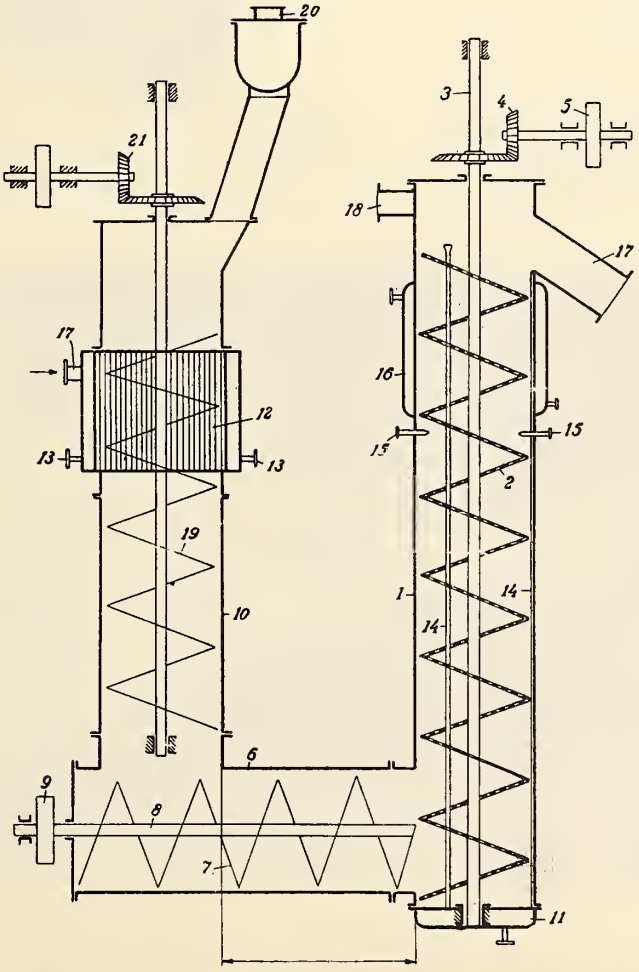

Figure 7.-Extractor used in the Hildebrandt system. (Courtesy of Sieck and Drucker, Inc.)

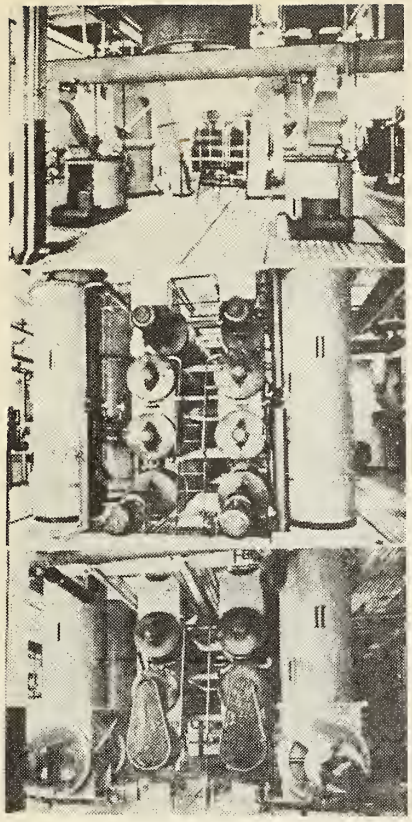

Figure 8.-An installation of two Hildebrandt extraction units. (Courtesy of Sieck and Drucker, Inc.)

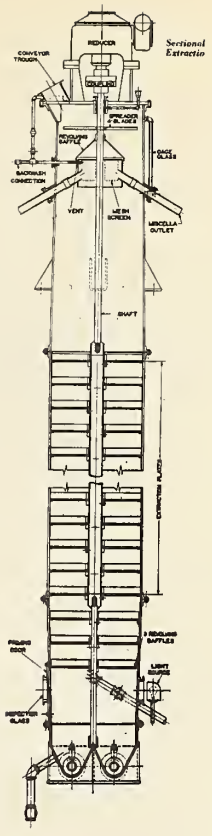

Figure 9.-The Allis-Chalmers extraction column. (Courtesy of Allis-Chalmers Manufacturing Co.)

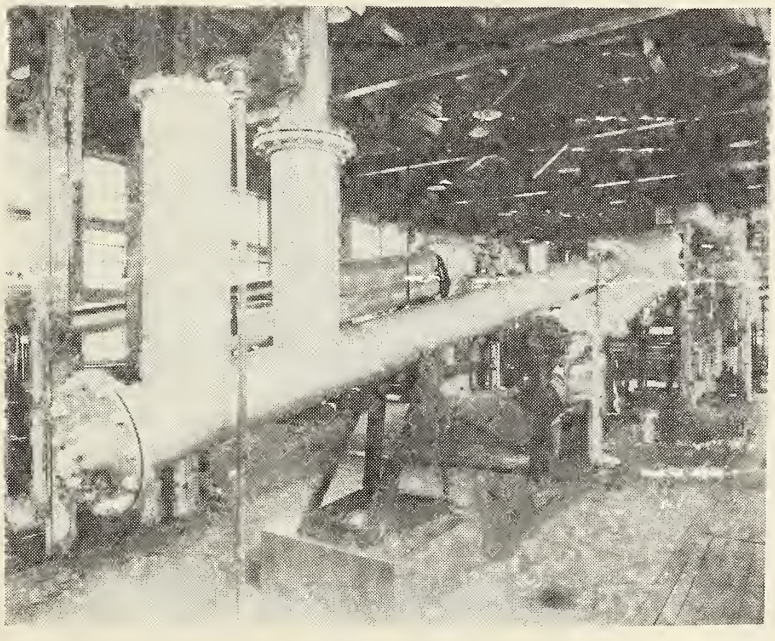

Figure 10.-Interior of one of the Ford Motor Company's soybean extraction plants. (Courtesy of Ford Motor Company.)